# VAPORIZATION COOLING OF ROTATING ELECTRICAL MACHINERY

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# PREFACE

The problems encountered in the current attempts to increase the power output of electric machines without a corresponding increase in size and weight have placed a growing burden upon machine cooling systems.

In order to prove the effectiveness of the revolutionary vaporization cooling process the authors of this paper have conducted laboratory tests at the United States Naval Postgraduate School during the period from January 1951 to June 1951.

The bulk of the information concerning vaporization cooling has been drawn from a paper on the subject by Mr. T. de Koning. The authors are also indebted to Professor C. V. O. Terwilliger of the Electrical Department of the U. S. Naval Postgraduate School for his ready assistance and guidance.

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## SYMBOLS AND ABBREVIATIONS

### Symbols

$< n$ greater than

$n <$ less than

### Abbreviations

n - an arbitrary power of current in load-temp relationship.

T - temperature - $^{o}F$

BTU - British thermal units

h - heat transfer coefficient

## CHAPTER I

## INTRODUCTION - THE FUNDAMENTALS OF VAPORIZATION COOLING

Effective heat removal has always been of prime importance in the design and operation of electric machines. Losses in any electric machine are manifested in heat generated within this equipment, and unless effectively removed result in prohibitively high temperatures. Circulation of air in and around the machines has long been and still is standard practice. Hydrogen cooling has more recently been adopted for some installations.

The current trend toward running machines at higher loads, and higher temperatures, by improving the insulation temperature-wise is receiving a great deal of attention. There is some doubt however if this basic principle is a sound one in a long range sense. Since copper losses increase as the square of the current, we would expect the temperature of the machine to vary as some power, $n (1 < n < 2)$ of the current. If we are operating a motor at some temperature $T_1$ that exists at full load and then increase the load by 25%, the temperature of course will rise. As illustrated in figure 1, in conventional machines $T_1$ is relatively low and the slope of the curve of temperature versus load is moderate. Therefor an increase of load by 25% will not give an unduly large increase in temperature and it is common practice to build machines to run at 125% of full load for short periods.

Suppose now we have insulation that will withstand


FIG 1 - LOAD Vs TEMPERATURE CHARACTERISTICS

higher temperatures and we run the machine at a higher temperature $T_3$, existing at full load. The slope of our curve of load versus temperature is steeper here, and an increase of 25% in load will increase the temperature a great deal more than was experienced in the first instance. In order to retain the same degree of reliability as that available in the first machine, the insulation must be designed to withstand this much higher temperature. Since the relation between temperature and load is much more critical at the higher temperatures it becomes evident that although the available power output of the initial machine has been increased by increasing operating temperature, the power continuously available is considerably less than one would first assume considering only the maximum insulation temperature $T_4$.

Another rather obvious drawback is that the operating temperature will vary quite widely due to minor derangements of the cooling system. Considering figure 1 again it may be seen that the consequences may become quite serious during high temperature operation if a cooling derangement would shift the temperature vs load curve to some higher power such as $T = KI^{n^1}$. There are of course many mechanical arguments against higher operating temperatures.

At the winter meeting of the AIEE in 1949, Mr. T. de Koning presented a paper entitled "Vaporization Cooling of Large Electric Machines" in which he introduced the idea of and arguments for cooling electric machines by the

vaporization of water.

When water vaporizes, it absorbs approximately 1000 B.T.U.'s of energy with no increase in temperature. The temperature at which this vaporization takes place is dependent upon the pressure. Applying this effect to the cooling of electric machines, if it is desired to maintain the air gap temperature of a motor at 150°F, the pressure around the motor may be reduced to approximately 7.5 inches of mercury absolute. Water may then be admitted to the air gap of the machine. Each pound of water so introduced will absorb approximately 1000 B.T.U.'s of energy and will thus carry away the waste heat of the motor. At a pressure of 4 inches of mercury the saturation temperature of water is 125.4°F and at 2 inches of mercury it is 101.1°F.

From this it appears that by controlling the rate of flow of water and the pressure in the motor, the air gap temperature may be maintained at any reasonable point. Since the air gap is adjacent to the region of high losses in a motor, it appears that the reduction of air gap temperature should have a material effect on the hot spot temperature of the machine.

CHAPTER II

COMPARISON OF COOLING MEDIA

Some of the advantages of vaporization cooling may be indicated by comparing the properties of the more common coolants, air and hydrogen, with those of water.

The specific heat of air is approximately .24 BTU per degree fahrenheit per pound. For a temperature rise of 80 degrees fahrenheit 19.2 BTU's are removed for each pound of air circulated through the motor. For hydrogen with a specific heat of 3.41 for a similar temperature rise 273 BTU's are removed for each pound of coolant. For water entering at 80 degrees fahrenheit and leaving as saturated steam at 145 degrees fahrenheit corresponding to a pressure of 6.68 inches of mercury, 1076 BTU's are removed per pound of entering water. This comparison is strikingly in favor of water as a coolant. One pound of water will carry away the same heat as 4 pounds of hydrogen or 56 pounds of air under reasonable operating conditions.

A comparison on the volume basis also favors water vapor. Air at 13.6 cubic feet per pound will carry away 1.41 BTU per cubic foot as compared with 9.85 BTU per cubic foot for water vapor at the previously indicated operating condition. This favorable comparison on a volume basis decreases with a decrease in operating pressure because of the large increase in specific volume of the vapor. At 4 inches of mercury (125.4 degrees fahrenheit) the ratio becomes 1.41 to 6.1, which is still quite impressive.

Another factor favoring vaporization cooling becomes immediately evident upon inspection of heat-transfer coefficients (h) for air, hydrogen, and water. For air h is 15-25 BTU per square foot per hour per degree fahrenheit, for hydrogen 25-40, for water 400-1200, and for vaporizing water and condensing steam 2000 or more. From this it appears that vaporization cooling will produce much more effective heat transfer from the hot areas to the coolant.

# CHAPTER III

## ADVANTAGES OF VAPORIZATION COOLING

A summary of the advantages possible with vaporization cooling includes the following items:

(1) Air gap temperature may be controlled through control of pressure and the quantity of water admitted.

(2) Weight of coolant used is much less than for other conventional coolants.

(3) Volume of coolant used is appreciably reduced compared to other coolants.

(4) Improved heat transfer between the source of heat and the cooling medium.

(5) If further cooling of the stator is necessary this may be accomplished by longitudinal cooling water tubes running the length of the stator.

# CHAPTER IV

## GROUNDS

The vital question concerning vaporization cooling concerns the possibility of "grounds". An analysis of this problem gives promise that the difficulty can be overcome. It is recommended that distilled water be used as the coolant. Since distilled water is a good insulator it is conceivable that in a clean machine, the coolant, even if it existed as water and came in contact with the windings, would not cause a ground. Such cleanliness will not exist unless extreme care is taken toward this end. Secondly, the entry of water must be controlled by a thermostatic and pressure control valve so that no more water will be delivered than is necessary to maintain the air gap at saturation or slightly superheat temperature. This would preclude the possibility that some of the coolant would remain in the air gap as water.

Since the water will enter the air gap as a fine spray, or be quickly broken into minute droplets upon striking the moving rotor, vaporization will begin immediately. Indeed the water should flash almost instantly upon entry. Should there be a tendency for moisture to collect and seep in through the insulation it will be moving toward a region of higher temperature and will be vaporized and driven off before reaching the conductor.

Arrangements must be made for purging the system of all vapor each time the machinery is secured. This is

necessary to prevent condensation on machine parts as the internal pressure is allowed to increase. A little care and thoughtfullness in preparing an operating and maintenance check off list should insure reasonable ground readings at all times.

## CHAPTER V

## PROPOSED VAPORIZATION COOLING INSTALLATION

The proposed installation for vaporization cooling would be adaptable to medium and large size machines and would consist of the following:

(1) A completely enclosed machine with a shaft seal suitable for operation at about 4 inches of mercury absolute pressure.

(2) A water distribution system to provide coolant in the air gap as a fine spray or in drops impinging on the rotor. The distribution may also provide water at any other locations where cooling is desired.

(3) A metering system probably similar to injectors on our present day diesel engines.

(4) A thermostatic and pressure control system controlling the metering system.

(5) Evacuating equipment that would maintain the desired pressure in the machine casing.

(6) A condenser for condensing the coolant vapor.

(7) A condensate pump to remove the condensed coolant.

(8) Filters to remove impurities from the condensate and preserve cleanliness in machine.

## CHAPTER VI

## GENERAL DESCRIPTION OF LABORATORY TESTS

It was the purpose of this work to initiate an investigation of the effectiveness of vaporization cooling with a view toward running a motor at loads above full load with little or no increase in the temperature attained when the motor was operated at rated load, in the conventional manner. To do this conventional direct current and induction motors were used, loaded with a brake and a generator through a resistance bank. The motor was inclosed in an airtight box with the motor shaft going through a conventional water lubricated packing gland. Vacuum was maintained with an eductor with water supplied by a centrifugal pump, outlet pressure 55-60 psi. Since the amount of water necessary for cooling was very small, no attempt was made to recover the condensate. Vapor was removed by the eductor and remained in that system. Iron-constantan thermocouples were installed in appropriate locations. Thermocouple readings were taken with a standard type potentiometer using a cadmium standard cell, dry cell, and galvonometer. See figure 2.

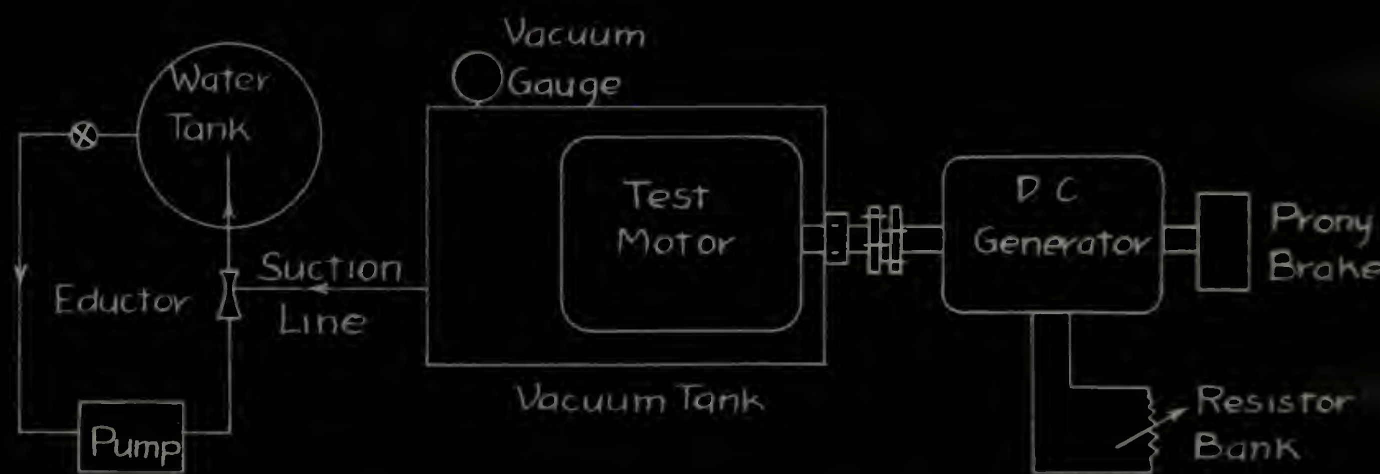



FIG. 2 - DIAGRAM OF TEST EQUIPMENT.

## CHAPTER VII

## DISCUSSION OF TESTS ON DIRECT CURRENT MOTOR

The direct current motor was an old machine rated at 1.75 horsepower. Three thermocouples were installed; one between the pole winding and core, one in the exit stream of vapor from the air gap and near the commutator, and the other about half way down and on the side of the armature slot. The leads from the latter were led through an axial hole in the rotor shaft, to a set of silver plated collector rings. Two copper-graphite brushes in parallel were used on each ring to minimize ripple in the voltage readings. Since our method of measuring thermal voltages balanced these voltages against a known voltage, there was no current flow through the thermocouple and no potential drop at the sliding contacts. There was undoubtedly an additional thermal introduced at the collector rings due to variations in tension of the brush springs and to the difference in diameter of the collector rings. Since we were concerned more with duplication of readings than with actual accuracy, no attempt was made to determine the temperatures of the rings and brushes and correct our readings accordingly. In any event the error would be quite small.

Holes were drilled radially through two pole cores and 1/8" copper tubing was inserted for the introduction of water to the air gap for vaporization. An attempt was made to control the rate of entry of the water by varying the size of an orifice in the tube but this proved unsatisfactory.

The rate of water entry was finally controlled manually by clamps on rubber tubing. No attempt was made to introduce the water as a fine spray. See figure 3.

The machine was initially run at rated load with normal cooling until armature temperature ceased to rise. Exit air temperature from the air gap was also constant and the pole temperature was nearly so. See figure 5.

The next run was made at rated load with the box sealed and vaporization cooling. Water was not introduced until the temperature was high enough to insure that vaporization would take place. Effective cooling was evident by observing the immediate drop in armature temperature. See figure 5. Pole temperature and exit vapor temperature continued to rise but this was of no immediate concern since water was being introduced only in the air gap. Pressure in the box for this run was 6.5″hg.

When the motor was stopped, the pressure in the box was allowed to build up to atmospheric pressure, no attempt being made to purge the box of vapor. Ground readings were taken and found to be: armature circuit-50,000 ohms, field circuit-2 megohms. Certainly a part of this ground was due to condensation of the water vapor, probably around the commutator and brushes. The necessity of a system to purge the box of vapor when the machine is secured was evident.

The next run was made at 25% overload on the motor. Here the results were not so gratifying. Armature temperature could not be controlled. This was probably due to three

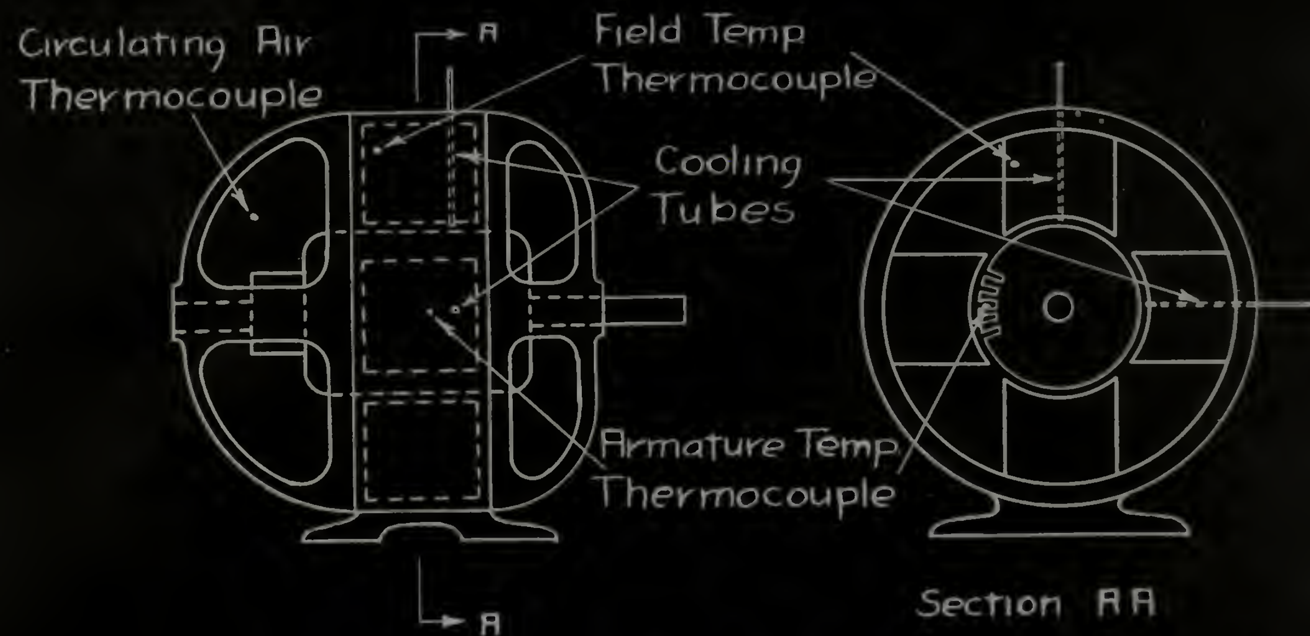



FIG. 3 -LOCATION OF COOLING TUBES AND THERMOCOUPLES-D.C. MOTOR TEST.

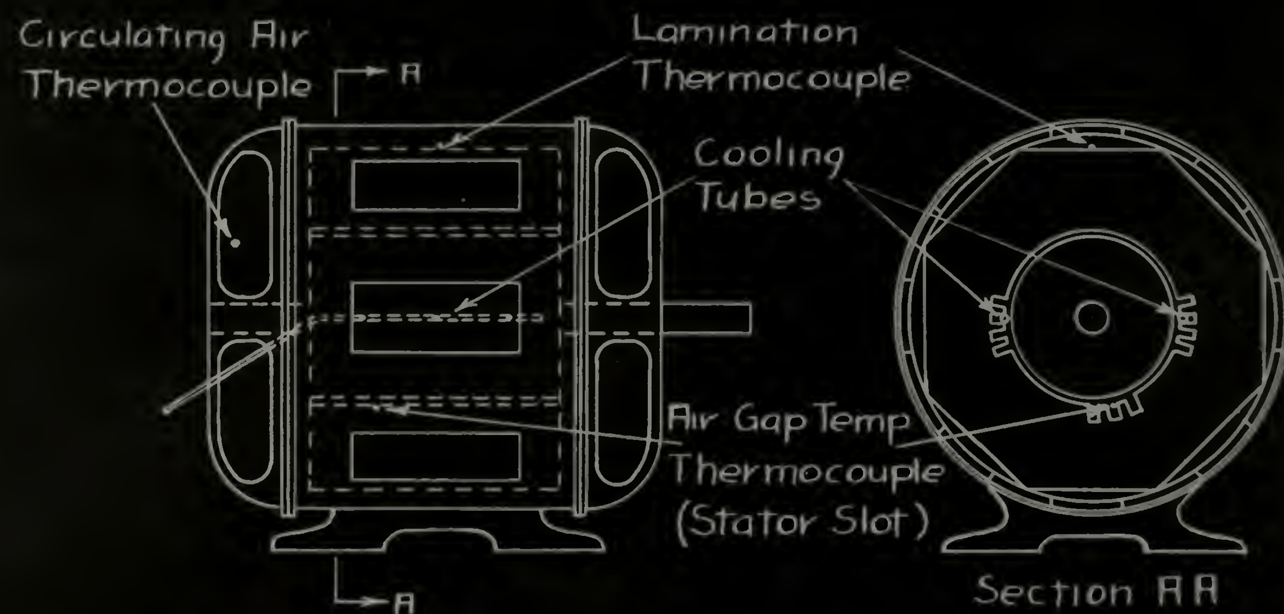



FIG. 4- LOCATION OF COOLING TUBES AND THERMOCOUPLES FOR INDUCTION MOTOR TEST.

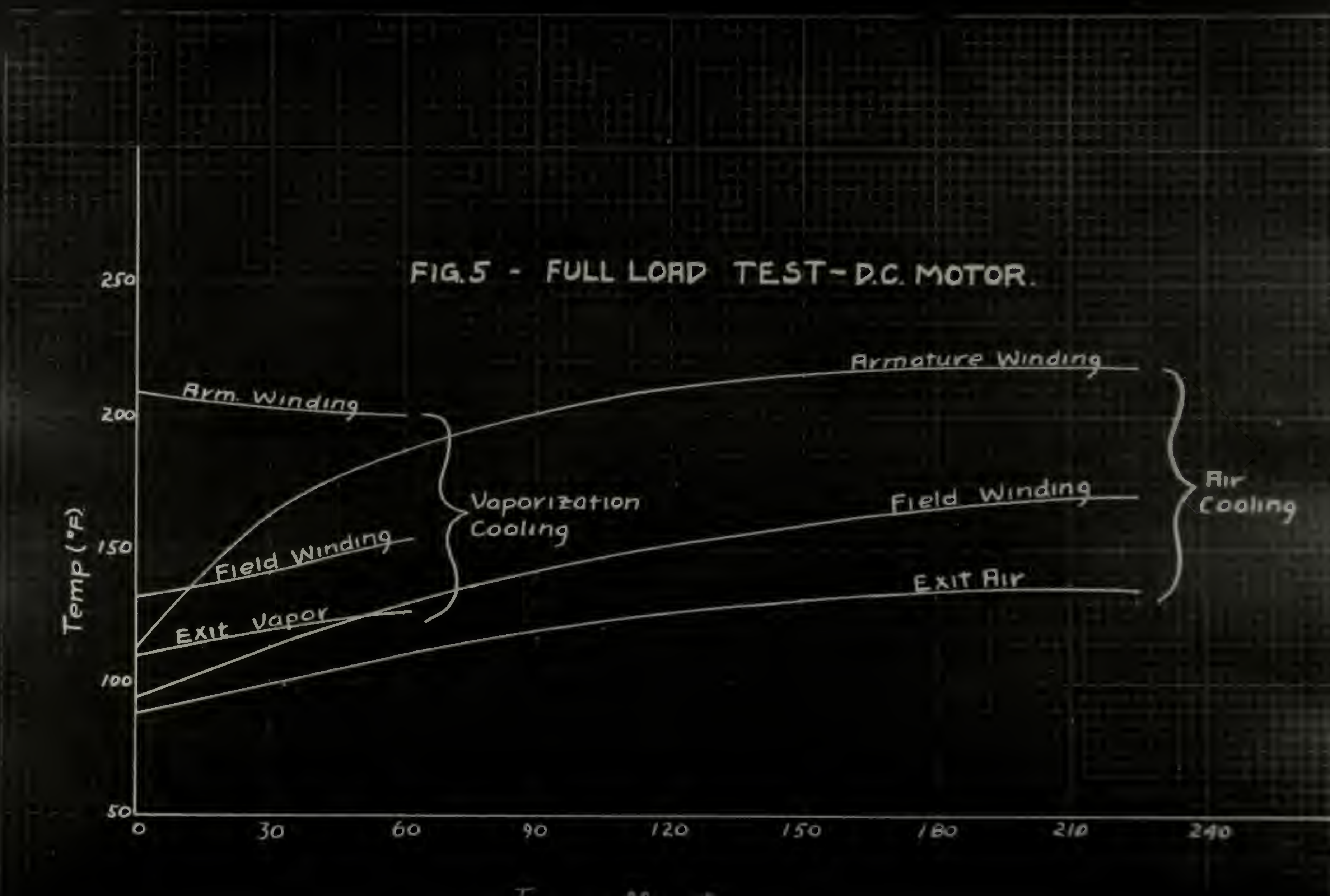


FIG.5 - FULL LOAD TEST-D.C. MOTOR.
Temp (°F)
250
200
150
100
50
0
30
60
90
120
150
180
210
240
Arm. Winding
Field Winding
Exit Vapor
Vaporization
Cooling
Armature Winding
Field Winding
Exit Air
Air
Cooling

things: (1) The water was not being confined to the air gap long enough for vaporization to take place. Since the water was being admitted as a fine stream rather than a spray, appreciable time was necessary for vaporization to take place. The centrifugal force imparted to the water drops by the rotor was throwing the water away from the main heat generating surface and into the cavities between the poles. (2) With our evacuating equipment we could not maintain a pressure low enough to sufficiently accelerate vaporization to control the temperature at the desired level. (3) More heat than would normally be expected was caused by poor commutation at loads above full load. In attempting to decrease the pressure in the box, it was accidentally flooded. A squirrel cage induction motor was then installed, thus relieving the experiment of two of the difficulties mentioned above.

# CHAPTER VIII

## DISCUSSION OF TESTS ON INDUCTION MOTOR

Three thermocouples were installed in the induction motor; one on the outside of the motor against the laminations (3/8" from bottom of armature slot), one in the exit stream of air (or vapor) from the air gap, and one in the slot opening adjacent to the air gap. There was insufficient room in the slots of this motor to install a thermocouple inside the slot. Hence the temperature read by the thermocouple in the slot opening will approximate the air gap temperature rather than the hot spot temperature. Collector rings were not necessary since no thermocouple was installed in the rotor.

Water was introduced on opposite sides of the armature through small plastic tubes located in the slot openings. Each tube had 3 - .030" diameter holes drilled along its length. Again no effort was made to introduce the water as a fine spray. See figure 4.

As in the d.c. motor, runs were made at rated load with normal cooling. See figures 6 and 7.

Subsequent runs were made and the following data taken after approximately one hour of operation.

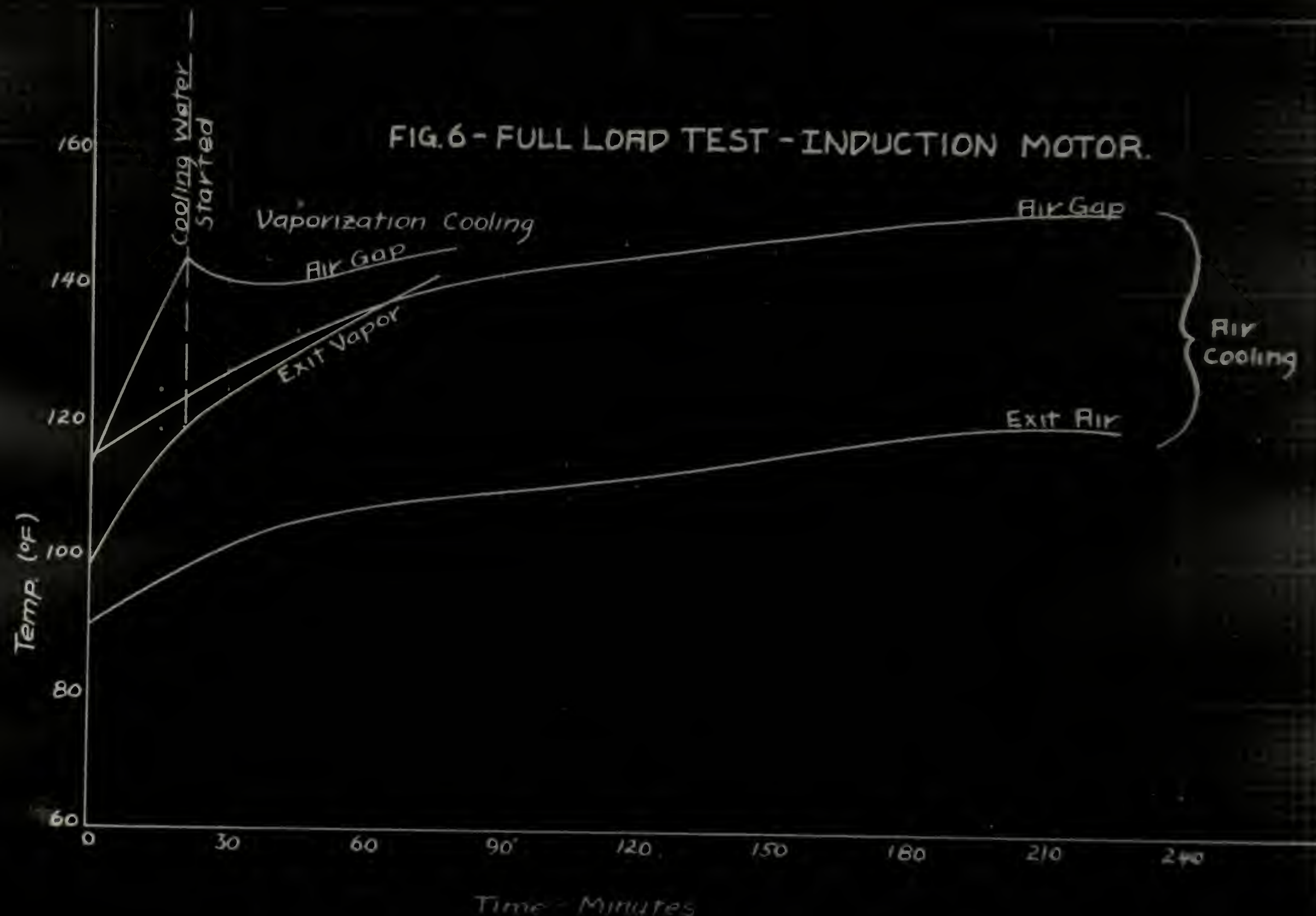


FIG. 6 - FULL LOAD TEST - INDUCTION MOTOR.
Cooling Water Started
Vaporization Cooling
Air Gap
Exit Vapor
Air Gap
Exit Air
Air Cooling
Temp. (°F)
160
140
120
100
80
60
0
30
60
90
120
150
180
210
240
Time - Minutes

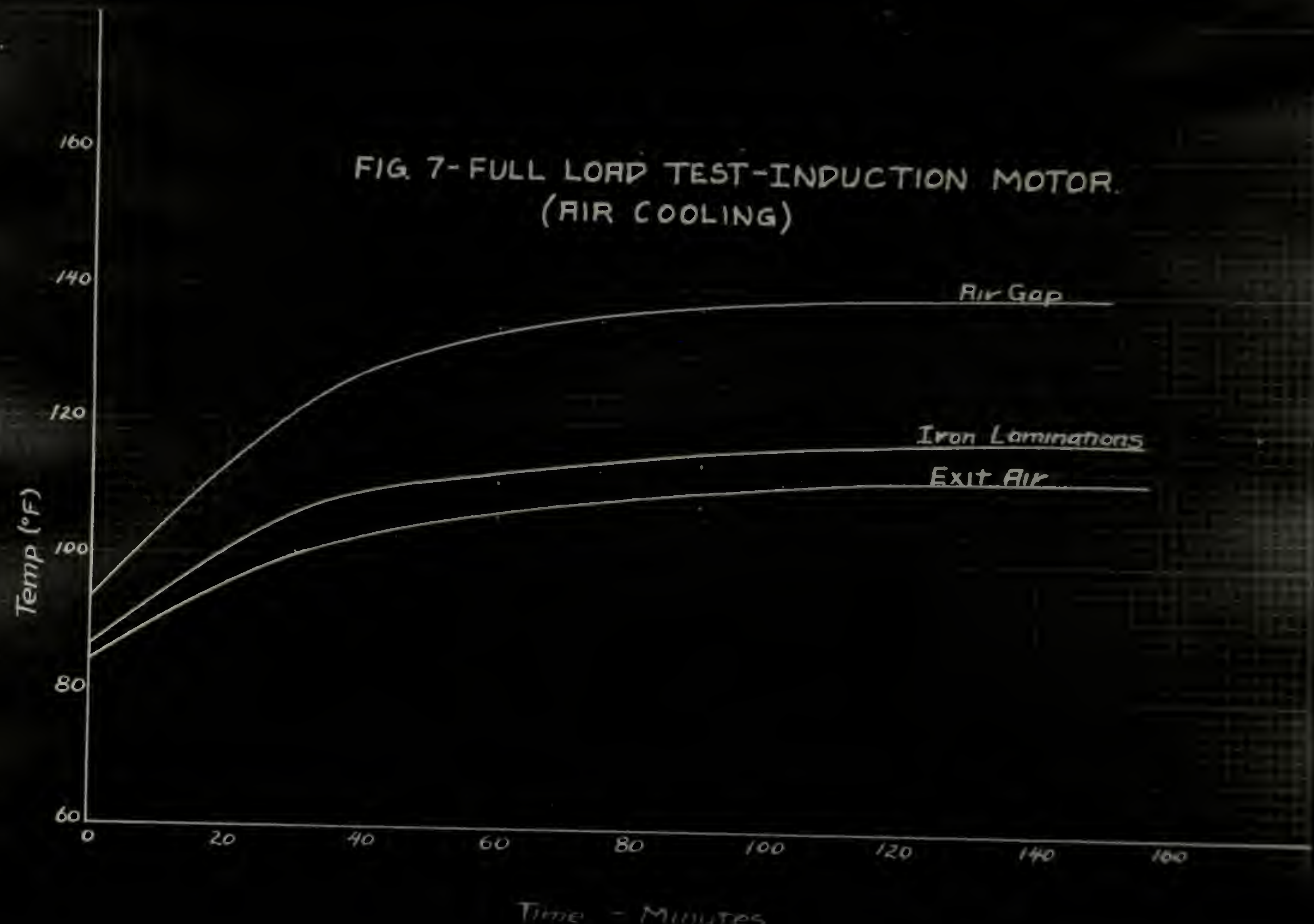


FIG. 7 - FULL LOAD TEST - INDUCTION MOTOR.
(AIR COOLING)
Air Gap
Iron Laminations
Exit Air
Temp (°F)
160
140
120
100
80
60
0
20
40
60
80
100
120
140
160
Time - Minutes

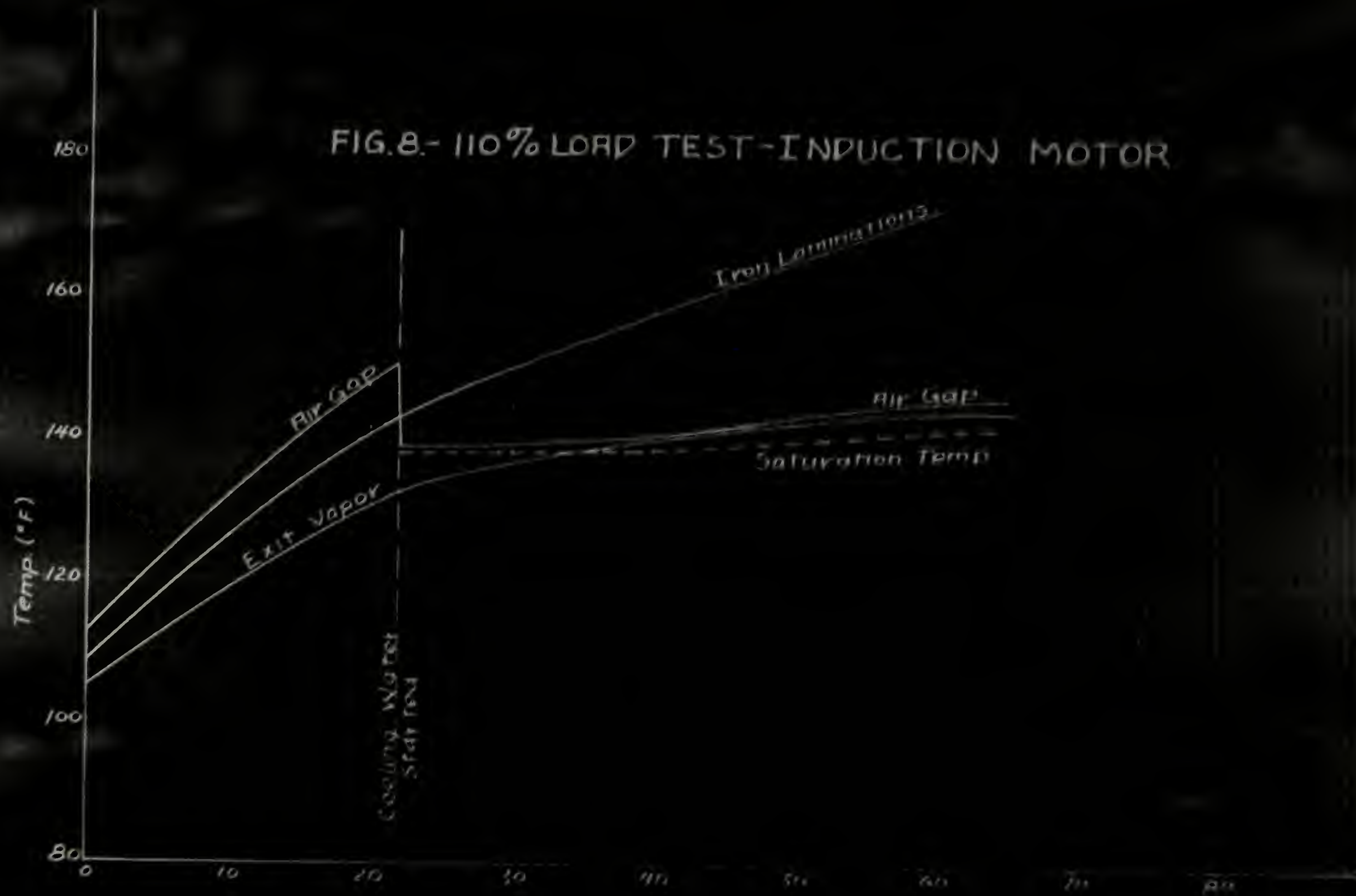
| % Full Load | Temperatures | | |
|---|---|---|---|
| | Air Gap | Exit Vapor | Laminations |
| 110 | 146°F(Controlled) | 144°F(Steady) | 172.5°F(Rising) |
| 125 | 154°F " | 160°F " | 186.5°F(Steady) |
| 150 | 152.5°F " | 181°F(Rising) | 252°F(Rising) |
| 200 | 144°F " | 156°F " | *200°F(Controlled |

* water drip on laminations near thermocouple

Results of these runs are shown in figure 8 to figure 11. Water injection was not begun until the temperature was high enough to insure vaporization. Attention is invited to the saturation temperature curve plotted for these runs and how closely the air gap temperature follows this saturation curve. Undoubtedly the condition in the air gap was such that wet steam existed there. With automatic pressure-temperature controlled metering it would be advantageous to work with a few degrees superheat as insurance against moisture. It must be emphasized that at all times the air gap temperature was controlled only by varying the rate of water flow. Had means been available to maintain a higher vacuum there appears to be no reason why the temperature could not be controlled at an even lower value.

Attention is invited to the very high temperatures reached in the iron laminations, and the fact that this temperature was still rising. There are several practical ways that the iron could be cooled. Further applying the principle of vaporization, a water drip was installed about 3" from the thermocouple on the final run at 200% full load.

FIG. 8.- 110% LOAD TEST-INDUCTION MOTOR



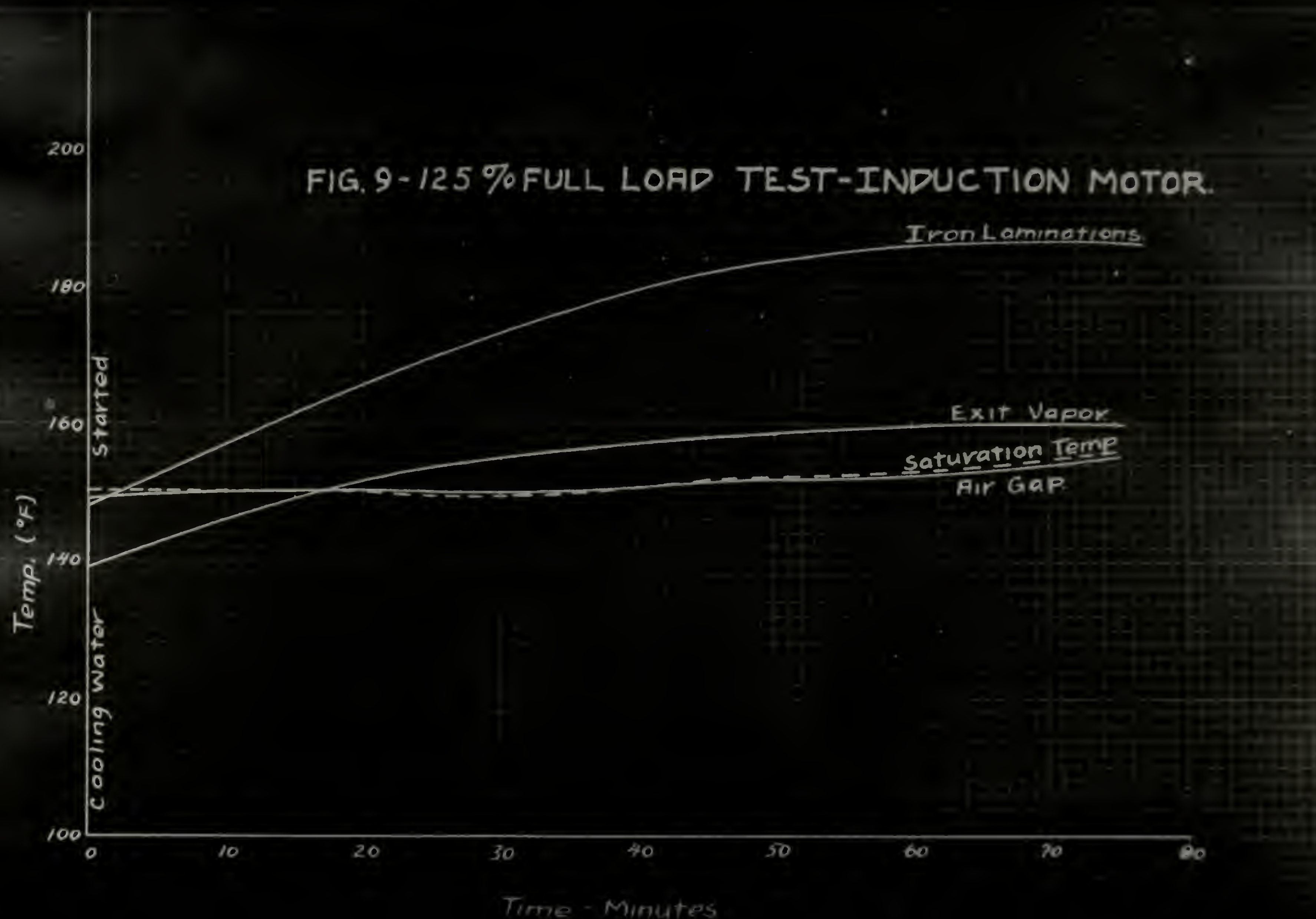



FIG. 9 - 125 % FULL LOAD TEST-INDUCTION MOTOR.

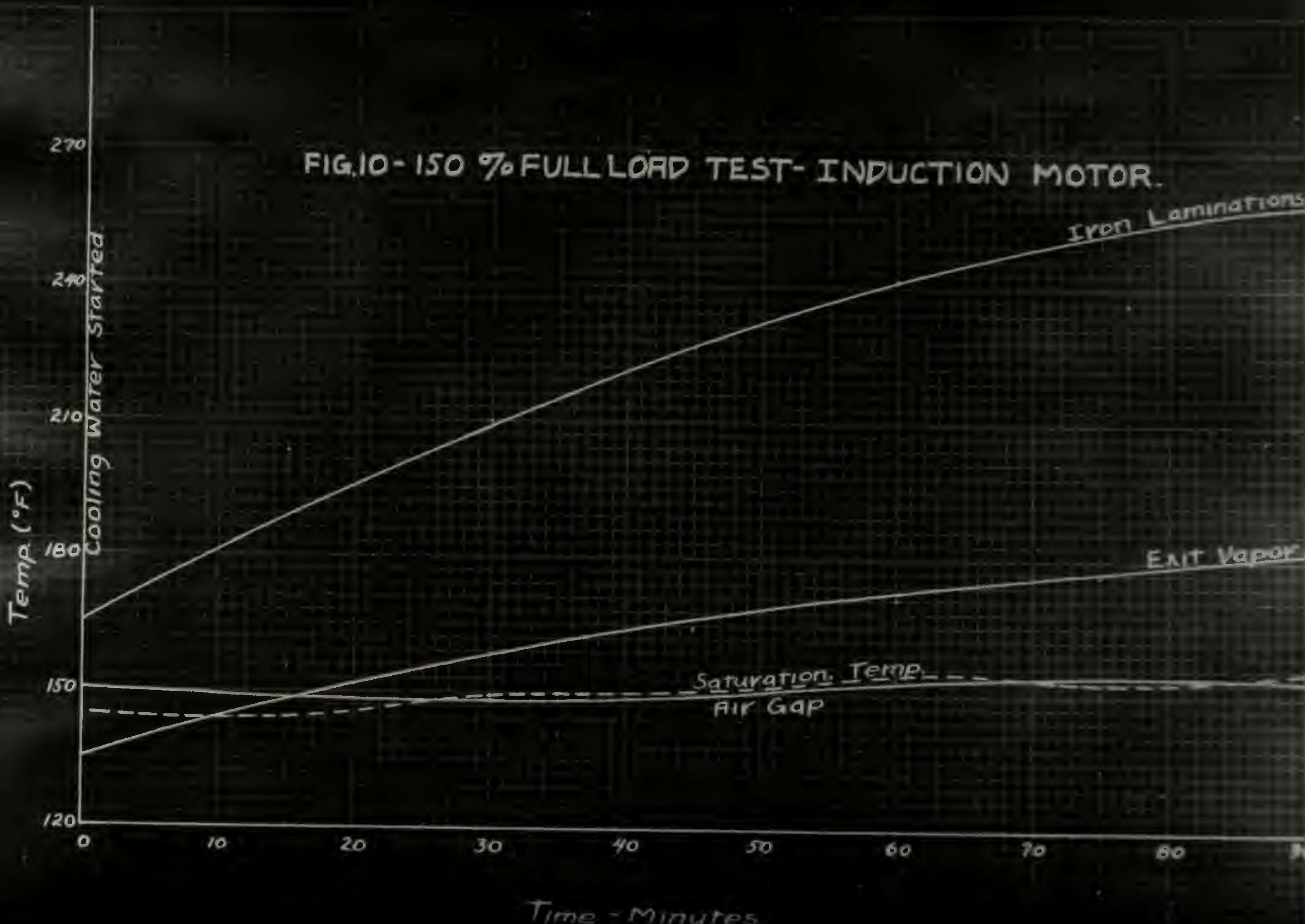



FIG. 10 - 150 % FULL LOAD TEST - INDUCTION MOTOR.

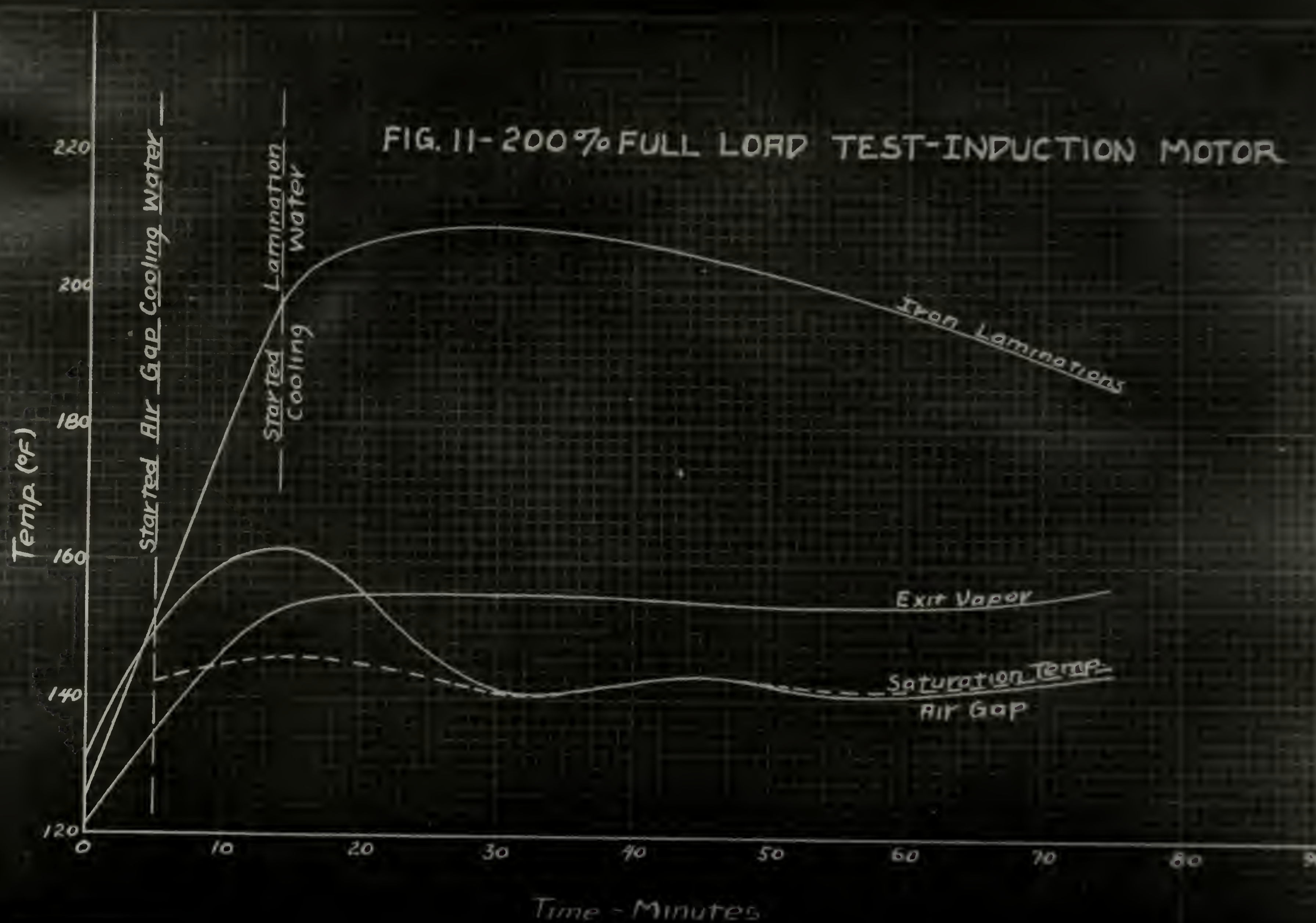



FIG. 11 - 200% FULL LOAD TEST-INDUCTION MOTOR

The results were again gratifying as shown in figure 11. Certainly if the air gap temperature can be controlled, the outside of the motor can be controlled in a similiar manner.

The hot spot temperature can be very closely estimated. Very little heat was dissipated on the outside of the motor. The evacuated condition of the box precludes much heat loss by convection. Radiation losses are negligible. Some loss was certainly due to a very small amount of water leakage around the gland seal. This water was thrown out by the shaft and certainly some of it found its way to the outside of the stator. A fair approximation of the heat lost in this manner is probably about 5% of the heat generated. This would give a temperature gradient of .02°F from the bottom of the slot to the outside of the laminations at full load, steady state conditions. From this it is probable that the hot spot temperature was about 10-15°F higher than the lamination temperature as shown in the curves.

Ground readings were taken before and after each run. Before the motor was cooled by vaporization, the armature resistance to ground was 2 - 3 megohms. At the conclusion of the runs resistance to ground was 250,000 - 300,000 ohms. After letting the pressure build up, resistance to ground dropped to 80,000 - 100,000 ohms. Purging was accomplished by continuously running the evacuating equipment and venting the box to atmosphere through a 1/8" diameter hole. After purging in this manner for approximately one hour, the resistance to ground was increased to 2 - 3 megohms.

From these experiments it appears that vaporization cooling should be further investigated and that it offers great possibilities as a means of effective heat removal. Ground readings taken could certainly be improved with controlled injection of water and using insulation that is more moisture resistant.

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# APPENDIX A

## MACHINE NAME PLATE DATA

Electro-Dynamic Co.

Interpole Motor

| | | |
|---|---|---|
| 110 Volts | Frame S | Serial 15873 |
| 650-1300 RPM | $1\frac{3}{4}$ Hp. | 8 Amps. Cont. |
| | $2\frac{1}{4}$ Hp. | 9.5 Amps. 2 hours |

Westinghouse Line Start Induction Motor

| | | | |
|---|---|---|---|
| Type CS | Constant Speed | | |
| Cont. Rating | Full Load | $40^{\circ}$C Rise | Class 1 |
| Style 1077592 | Serial 2840 | Frame 324 | |
| Hp. 5 | 3 phase | 60 cycle | 220/440 Volts |
| Amps. 14.2/7.1 | | 870 RPM | |

D.C. MOTOR TEST

Full Load - Air Cooling

4 April 1951

| Time (Min) | $I_a$ amps | $I_f$ amps | Arm. Temp. m.v. | °F | Field Temp m.v. | °F | Exit m.v. | Air Temp °F |
|---|---|---|---|---|---|---|---|---|
| 0 | 8.1 | 1.15 | 2.30 | 112.5 | 1.74 | 94.0 | 1.56 | 88.0 |
| 15 | 8.2 | 1.10 | 3.10 | 140.0 | 2.00 | 102.8 | 1.72 | 93.5 |
| 30 | 8.0 | 1.14 | 3.76 | 162.3 | 2.31 | 113.2 | 1.92 | 100.5 |
| 45 | 8.0 | 1.10 | 4.11 | 174.2 | 2.52 | 120.8 | 2.03 | 103.5 |
| 60 | 8.0 | 1.10 | 4.45 | 186.0 | 2.79 | 129.5 | 2.21 | 110.0 |
| 75 | 8.0 | 1.12 | 4.70 | 194.0 | 2.98 | 136.0 | 2.32 | 114.0 |
| 90 | 8.0 | 1.10 | 4.93 | 201.3 | 3.12 | 141.0 | 2.40 | 116.5 |
| 105 | 8.0 | 1.12 | 5.08 | 205.5 | 3.28 | 146.2 | 2.57 | 120.5 |
| 120 | 8.0 | 1.12 | 5.22 | 210.0 | 3.43 | 151.0 | 2.70 | 126.5 |
| 135 | 8.0 | 1.13 | 5.32 | 212.5 | 3.55 | 155.0 | 2.76 | 129.0 |
| 150 | 8.0 | 1.15 | 5.40 | 215.0 | 3.65 | 158.8 | 2.85 | 131.5 |
| 165 | 8.0 | 1.15 | 5.46 | 217.0 | 3.78 | 162.8 | 2.87 | 131.5 |
| 180 | 8.0 | 1.15 | 5.51 | 218.5 | 3.85 | 165.0 | 2.87 | 133.5 |
| 195 | 8.0 | 1.17 | 5.54 | 219.0 | 3.94 | 168.5 | 2.98 | 136.0 |
| 210 | 8.0 | 1.16 | 5.53 | 218.7 | 4.01 | 171.0 | 3.02 | [illegible] |
| 225 | 8.0 | 1.14 | 5.52 | 218.6 | 4.05 | 172.0 | 2.82 | [illegible] |

APPENDIX B

# D.C. Motor Test
## Full Load - Vaporization Cooling

6 April, 1951

| Time (Min) | $I_a$ amps | $I_f$ amps | Vac. "Hg (g) | Arm Temp m.v. | Arm Temp °F | Field Temp m.v. | Field Temp °F | Exit Vapor Temp m.v. | Exit Vapor Temp °F |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 8.0 | 1.35 | 21 | 5.15 | 207.2 | 2.9 | 133.8 | 2.2 | 109.5 |
| 15 | 8.0 | 1.55 | 21 | 5.05 | 204.5 | 2.9 | 133.8 | 2.28 | 112.0 |
| 30 | 8.0 | 1.50 | 20.8 | 5.00 | 204.0 | 3.1 | 140.0 | 2.48 | 119.0 |
| 45 | 8.0 | 1.60 | 20.4 | 4.92 | 201.0 | 3.32 | 147.5 | 2.60 | 123.0 |
| 60 | 8.0 | 1.65 | 20.2 | 4.86 | 199.2 | 3.50 | 153.5 | 2.66 | 125.4 |
| | | (UNSUCCESSFULL OVERLOAD TESTS FOLLOW) | | | | | | | |
| 0 | 10 | 1.63 | 21 | 4.74 | | 3.26 | | 2.46 | |
| 15 | 10 | 1.54 | 21 | 5.39 | | 3.26 | | 2.53 | |
| 30 | 10 | 1.53 | 21.2 | 5.79 | | 3.34 | | 2.62 | |
| 35 | 10 | Stopped to Clean Nozzles | | | | | | | |
| | | | | | | | | | |
| 0 | 10 | 1.57 | 20.4 | 5.25 | | 3.19 | | 2.70 | |
| 5 | | Secured to fill water reservoir. | | | | | | | |
| 20 | 10 | 1.52 | 21.2 | 5.05 | | 3.30 | | 2.73 | |
| 35 | 10 | 1.47 | 20.7 | 5.92 | | 3.30 | | 2.76 | |
| | | | | | | | | | |
| 9 April/51 | | | | | | | | | |
| 0 | 8.5 | 1.65 | 24.6 | 2.34 | | 1.52 | | 1.46 | |
| 15 | 9.0 | 1.52 | 24.6 | 3.54 | | 1.71 | | 1.65 | |
| Started cooling 30 | 9.0 | 1.45 | 24.4 | 4.75 | | 2.05 | | 1.70 | |
| 45 | 9.0 | 1.46 | 24.1 | 5.5 | | 2.30 | | 2.10 | |
| 60 | 9.0 | 1.46 | 23.8 | 5.85 | | 2.60 | | 2.34 | |
| 75 | 9.0 | 1.56 | 23.5 | 6.01 | | 2.80 | | 2.48 | |
| [illegible] | 9.0 | 1.64 | 23.4 | 6.15 | | 2.88 | | 2.55 | |

APPENDIX B

Induction Motor Test
Full Load - Air Cooling

24 April 1951

| Time (Min) | $I_{phase}$ amps | Air Gap Temp m.v. | Air Gap Temp °F | Exit Air m.v. | Exit Air °F |
|---|---|---|---|---|---|
| 0 | 14.2 | 2.04 | 114.0 | 1.61 | 89.5 |
| 15 | 14.2 | 2.46 | 118.2 | 1.82 | 97.0 |
| 30 | 14.2 | 2.71 | 127.0 | 1.95 | 101.0 |
| 45 | 14.2 | 2.88 | 132.8 | 2.08 | 105.5 |
| 60 | 14.2 | 2.97 | 135.5 | 2.11 | 106.5 |
| 75 | 14.2 | 3.05 | 138.5 | 2.16 | 108.3 |
| 90 | 14.2 | 3.12 | 141.0 | 2.18 | 108.8 |
| 105 | 14.2 | 3.18 | 143.0 | 2.18 | 108.8 |
| 120 | 14.2 | 3.21 | 144.0 | 2.24 | 110.8 |
| 135 | 14.2 | 3.23 | 144.5 | 2.29 | 113.0 |
| 150 | 14.2 | 3.26 | 145.6 | 2.37 | 115.5 |
| 165 | 14.2 | 3.36 | 149.0 | 2.42 | 117.0 |
| 180 | 14.2 | 3.40 | 150.0 | 2.46 | 118.5 |
| 195 | 14.2 | 3.42 | 151.0 | 2.50 | 120.0 |
| 210 | 14.2 | 3.44 | 151.8 | 2.51 | 120.5 |
| 225 | 14.2 | 3.44 | 151.8 | 2.49 | 119.5 |

# Induction Motor Test
## Full Load - Air Cooling

1 May 19[illegible]

| Time (Min) | I phase amps | Air Gap Temp m.v. | Air Gap Temp °F | Iron Lam. Temp m.v. | Iron Lam. Temp °F | Exit Air Temp m.v. | Exit Air Temp °F |
|---|---|---|---|---|---|---|---|
| 0 | 14.2 | 1.71 | 93.0 | 1.51 | 86.3 | 1.46 | 84.5 |
| 15 | 14.2 | 2.20 | 109.5 | 1.84 | 97.5 | 1.71 | 93.0 |
| 30 | 14.2 | 2.55 | 121.5 | 2.14 | 102.5 | 1.93 | 100.5 |
| 45 | 14.2 | 2.74 | 128.0 | 2.20 | 109.5 | 2.00 | 103.0 |
| 60 | 14.2 | 2.91 | 134.0 | 2.25 | 111.0 | 2.10 | 106.0 |
| 75 | 14.2 | 2.95 | 135.0 | 2.30 | 113.0 | 2.14 | 107.8 |
| 90 | 14.2 | 3.00 | 137.0 | 2.32 | 114.0 | 2.15 | 108.0 |
| [illegible] | 14.2 | 3.03 | 137.5 | 2.41 | 116.8 | 2.27 | 112.3 |
| 120 | 14.2 | 3.03 | 137.5 | 2.43 | 117.5 | 2.26 | 112.0 |
| 135 | 14.2 | 3.06 | 139.0 | 2.45 | 118.0 | 2.23 | 110.5 |
| 150 | 14.2 | 3.08 | 139.5 | 2.50 | 120.0 | 2.27 | 112.3 |

APPENDIX B

Barom = 30.15 "Hg

25 April 19[illegible]

# Induction Motor Test - Full Load
## Vaporization Cooling

| Time (min) | $I_{phase}$ (amps) | Vac. in Hg (g) | Air Gap Temp. mv. | Air Gap Temp. °F | Exit Vapor Temp mv. | Exit Vapor Temp °F | | |
|---|---|---|---|---|---|---|---|---|
| 0 | 14.2 | 25.7 | 2.31 | 113.2 | 1.87 | 98.5 | | |
| 15 | 14.2 | 26.0 | 2.99 | 136.5 | 2.30 | 113.0 | | |
| 20 | started cooling | | 3.20 | 143.5 | 2.47 | 118.6 | | |
| 30 | 14.2 | 24.5 | 3.10 | 140.0 | 2.63 | 124.0 | | |
| 45 | 14.2 | 24.7 | 3.10 | 140.0 | 2.76 | 129.0 | | |
| 60 | 14.2 | 24.5 | 3.16 | 142.3 | 2.95 | 135.0 | | |
| 75 | 14.2 | 24.4 | 3.23 | 144.6 | 3.13 | 141.0 | | |

# Induction Motor Test

## 110% and 125% Full Load - Vaporiz. Cooling

Barom = 30.1" Hg

2 May 1951

| Time (Min) | Iphase amps | Air Gap Temp mv. | Air Gap Temp °F | Iron Lam. Temp mv. | Iron Lam. Temp °F | Exit Vapor Temp mv. | Exit Vapor Temp °F | Vac. in. Hg (gauge) |
|---|---|---|---|---|---|---|---|---|
| 0 | 15.6 | 2.28 | 112.5 | 2.16 | 108.3 | 2.06 | 105.0 | 24.6 |
| 15 | 15.6 | 3.00 | 137.0 | 2.90 | 133.0 | 2.56 | 122.0 | 24.7 |
| 20 | 15.6 | 3.38 | 149.8 | 3.14 | 141.5 | 2.82 | 131.0 | 24.7 |
| 22 | started cooling | 3.05 | 139.0 | 3.20 | 143.5 | 2.87 | 132.5 | 24.1 |
| 30 | 15.6 | 3.02 | 137.5 | 3.23 | 144.5 | 2.90 | 134.0 | 24.[illegible] |
| 45 | 15.6 | 3.25 | 145.0 | 3.71 | 160.5 | 3.16 | 142.0 | 24.4 |
| 60 | 15.6 | 3.26 | 145.5 | 4.08 | 173.0 | 3.24 | 144.5 | 24.0 |
| | cooling water rate = 40 drops/min (1/4" diam drops) | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | started cooling | | | | | | | |
| 0 | 17.8 | 3.36 | 149.0 | 3.33 | 148.0 | 3.07 | 139 | 22.5 |
| 15 | 17.8 | 3.40 | 150.0 | 3.73 | 161.5 | 3.38 | 149.5 | 22.5 |
| 30 | 17.8 | 3.39 | 149.8 | 4.03 | 171.5 | 3.55 | 155 | 22.6 |
| 45 | 17.8 | 3.44 | 151.8 | 4.40 | 184.0 | 3.63 | 158 | 22.[illegible] |
| 60 | 17.8 | 3.46 | 152.3 | 4.50 | 187.0 | 3.70 | 160 | 22.[illegible] |
| 75 | 17.8 | 3.55 | 155.0 | 4.35 | 182.0 | 3.71 | 160.5 | [illegible] |
| | cooling water rate = 74 drops/min (1/4" diam drops) | | | | | | | |

# Induction Motor Test

## 150 % and 200 % Full Load - Vaporiz. Cooling

Barom. 29.2 "Hg

3 May 19[illegible]

| Time (Min) | I phase (amps) | Air Gap Temp M.V. | Air Gap Temp °F | Iron Lam. Temp M.V. | Iron Lam. Temp °F | Exit Vapor Temp M.V. | Exit Vapor Temp °F | Vac. in. Hg [illegible] |
|---|---|---|---|---|---|---|---|---|
| started cooling 0 | 21.2 | 3.43 | 151.0 | 3.43 | 151.0 | 2.87 | 131 | [illegible] |
| 15 | 22.0 | 3.35 | 148.5 | 4.98 | 203.0 | 3.55 | 155 | [illegible] |
| 30 | 21.2 | 3.35 | 148.5 | 5.25 | 210.0 | 3.64 | 158.3 | [illegible] |
| 45 | 21.7 | 3.36 | 149.0 | 5.67 | 226.5 | 3.82 | 164.5 | [illegible] |
| 60 | 22.0 | 3.51 | 154.0 | 6.13 | 241.5 | 4.03 | 171 | [illegible] |
| 75 | 21.5 | 3.41 | 150.5 | 6.38 | 250.0 | 4.18 | 176.5 | [illegible] |
| 90 | 22.0 | 3.55 | 155.0 | 6.66 | 259.5 | 4.37 | 182.8 | [illegible] |
| | cooling water rate = 66 drops/min (1/4" diam. drop) | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| 0 | 27.5 | 2.81 | 131.0 | 2.65 | 125 | 2.53 | 121 | [illegible] |
| started cooling 5 | 28.0 | 3.40 | 150.0 | 3.25 | 145 | 2.94 | 134.8 | [illegible] |
| 15 | 28.0 | 3.73 | 161.5 | 4.95 | 202 | 3.53 | 154.5 | [illegible] |
| 30 | 27.0 | 3.14 | 141.0 | 5.14 | 209 | 3.57 | 155 | [illegible] |
| 45 | 27.5 | 3.19 | 143.5 | 4.97 | 203 | 3.52 | 154.[illegible] | [illegible] |
| 60 | 28.5 | 3.14 | 141.0 | 4.90 | 200 | 3.50 | 153.5 | [illegible] |
| [illegible] | [illegible] | 3.22 | 144.0 | 4.48 | 186.5 | 3.60 | 157 | [illegible] |

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